Braz Dent J (2004) 15(3): 214-219
ISSN 0103-6440

Effects of Aluminum-Copper Alloy Filtration on Photon Spectra, Air *Kerma* Rate and Image Contrast

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This study evaluated the performance of aluminum-copper alloy filtration, without the original aluminum filter, for dental radiography in terms of x-ray energy spectrum, air *kerma* rate and image quality. Comparisons of various thicknesses of aluminum-copper alloy in three different percentages were made with aluminum filtration. Tests were conducted on an intra-oral dental x-ray machine and were made on mandible phantom and on step-wedge. Depending on the thickness of aluminum-copper alloy filtration, the beam could be hardened and filtrated. The use of the aluminum-copper alloy filter resulted in reductions in air *kerma* rate from 8.40% to 47.33%, and indicated the same image contrast when compared to aluminum filtration. Aluminum-copper alloy filtration may be considered a good alternative to aluminum filtration.

Key Words: filtration, dental radiography, alloys.

INTRODUCTION

When taking radiographs, the association of the tube current, exposure time, kilovoltage and filtration of the x-ray beam are factors that modify the number of photons and the energy spectrum, thus affecting image quality.

Increasing filter thickness results in an increase in filtration, which means that there is removal of a great number of low energy photons from the x-ray beam, and when the filter is very thick, some of the higher energy photons that contribute to the radiographic image formation are also removed. In order to compensate for the loss of these high-energy photons it is necessary to increase exposure time (1), which causes tube loading degradation and reduces image contrast (2).

Several studies have been conducted with additional filtration, i.e., the use of Lanex Regular screen (3), samarium (3-5), gadolinium (3), erbium (6,7), yttrium (7,8), niobium (7,9). These studies tested which of them were the most effective at reducing x-ray exposure without reducing image quality and also which filter causes change in the x-ray energy spectrum without reducing image contrast. The relation among half-value layer, image contrast and x-ray exposure using these filters was also studied.

Therefore, the purpose of this study was to evaluate the performance of aluminum-copper alloy filtration with the removal of the original aluminum filter for dental radiography compared to aluminum filtration in terms of x-ray energy spectrum, air *kerma* rate (10,11) and image quality.

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MATERIAL AND METHODS

Radiography

The x-ray machine was a standard GE 100 (General Electric, Milwaukee, WI, USA) with equivalent filtration of 1.83 mm of aluminum and the focal spot-to-film distance was approximately 400 mm when using the standard acrylic device.

An acrylic device was used during x-ray film exposure for the purpose of maintaining a fixed focal spot-to-film distance and directing the central x-ray beam perpendicular to the object and the film.

Aluminum Step-wedge Phantom

We made an aluminum step-wedge with eight steps, with the following thicknesses: 2, 4, 6, 8, 10, 12, 14 and 16 mm (12).

Filters

Single-phase aluminum-copper alloy filters were made with different copper percentages (2%, 3% and 4% copper in alloy) and thicknesses, respecting the solubility and homogeneity range of the elements (Table 1).

Phantom Jaw

We also made a phantom section of the mandible, which had the first, second, and third molars embedded in acrylic resin to simulate soft tissue (13).

Exposure Time

The appropriate exposure time was adjusted with the 10 mm thickness of the step-wedge, thus showing an optical density of approximately 1.0, which is within the density range of dental tissues (3).

Radiography with step-wedge

Ten radiographs using the step-wedge were taken at 60 kVp and 70 kVp, 10 mA with Ektaspeed Plus film (Eastman Kodak, Rochester, NY, USA) for each aluminum-copper alloy filter thickness and percentage. Optical densities of the center area of each step were measured with an MRA densitometer (MRA, Ribeirão Preto, SP, Brazil), with a 2 mm aperture. Averages of optical densities were used to calculate contrast index accordingly to the formula (14): $C = D_2 - D_7 / 1/2 (D_2 + D_7)$, where D_2 (step = 4 mm) is one of the darkest step images and D_7 (step = 14 mm) is one of the lightest step images.

Radiography with phantom jaw

One periapical radiograph using Ektaspeed Plus film was taken with each thickness of the aluminum-copper alloy filter of the phantom jaw in agreement with the x-ray exposure time provided by the step-wedge. The x-ray films were identified with metal letters and numbers on their borders and manual processing was performed with Kodak GBX solutions (Eastman Kodak) according to Casati Alvares and Tavano (15), where 14 films were simultaneously processed together. Radiographs made of the phantom allowed comparison and subjective evaluation of the image quality. When subjective evaluations of image quality were conducted, the periapical radiographs were stored in a film mount and ten oral radiologists were asked to evaluate the radiographic images of the following areas: cemento-enamel junction in the distal surface of first left mandibular molar, apex of third left mandibular molar and periodontal ligament space of first left mandibular molar. The evaluations were done with a questionnaire that was circulated to the examiners and was drawn up based on Kapa and Tyndall (16). The examiners were asked to choose the best radiograph made with the aluminum filtration and then evaluate it against the others made with the aluminum-copper alloy filtration. After they had chosen the best one made with AlCu alloy filter they judged each

Table 1. Distribution of the aluminum-copper alloy (AlCu) thicknesses in millimeters, according to percentage.

AlCu alloy percentage	Thickness (mm)
2% AlCu	2.12
2% AlCu	2.28
3% AlCu	1.37
3% AlCu	1.76
3% AlCu	2.10
4% AlCu	1.24
4% AlCu	1.59
4% AlCu	2.33

chosen radiography on the basis of the following image-quality criteria: 1 = inadequate image, 2 = barely inadequate, 3 = adequate or 4 = more than adequate. The examiners repeated the radiographic assessment in-group to achieve a common opinion.

Photon spectrometry

The photon energy spectrometry, using aluminum filtration and aluminum-copper alloy filtration was made with Cadmium and Zinc Telluride detector with a special collimation system which was adapted by Becker (17), for the purpose of comparing the photon energy spectra by means of graphic construction.

Half value layer determination

The reproduction of the tube voltage and time exposure were measured with a Unfors Instruments type 9002 series 80961 (Billdal, Sweden) and a time exposure measurer (model CQ 03 series 03-110, Ribeirão Preto, SP, Brazil), respectively. Half-value layers (HVLs) were also measured with the method of adding thicknesses of aluminum. The thicknesses of aluminum-copper alloy and aluminum filters and exposure time were varied.

Air kerma rate

Air *kerma* rate in mGy was measured with a calibrated ionization chamber 10 x 5-6 cc, series 15-506 connected to a measurer model 9015 series 91-0271 (Radcal Corporation, Monrovia, CA, USA) at the end of the circular position-indicating device.

RESULTS

Radiography with step-wedge

The contrast index remained constant for the radiographic image (Table 2).

Radiography with phantom jaw

The examiners were asked to choose the best radiography made with the phantom jaw using aluminum filtration. The majority of the examiners chose the radiography taken with Ektaspeed Plus film and 60kVp. The chosen radiography was used as a standard for the future comparison with those taken with AlCu alloy filtration without the original aluminum filter.

The results showed that the 3% AlCu alloy filtration, Ektaspeed Plus film and 70 kVp produced radiographs chosen by the examiners as having radiographic image quality similar to or better than the best images taken with aluminum filtration.

Photon spectrometry

The results of the x-ray energy spectrum using standard aluminum filtration and aluminum-copper alloy filtration were recorded on graphs to evaluate x-ray

Table 2. Distribution of contrast index using Ektaspeed Plus film at 70 kVp, half-value layers (HVL in millimeters of aluminum equivalent) and air *kerma* rate (in mGy) and its respective percentage of reduction related to standard aluminum filtration and exposure time for aluminum copper alloy and aluminum filtration.

Type of the filter and thickness	Contrast index	HVL	Exposure time	Air *kerma* rate	Percentage of reduction related to aluminum filtration
Al - 1.83	1.02	2.5	0.6	3.93	-
2% AlCu -2.12	0.97	2.7	0.6	3.36	14.50
2% AlCu - 2.28	0.98	2.8	0.6	3.08	21.63
3% AlCu - 1.37	1.01	2.3	0.5	3.56	9.41
3% AlCu - 1.76	1.03	2.6	0.6	3.60	8.40
3% AlCu - 2.10	0.99	2.8	0.6	3.01	23.41
4% AlCu - 1.24	1.01	2.2	0.5	3.48	11.45
4% AlCu - 1.59	1.00	2.7	0.5	2.75	30.03
4% AlCu - 2.33	0.97	3.1	0.6	2.07	47.33

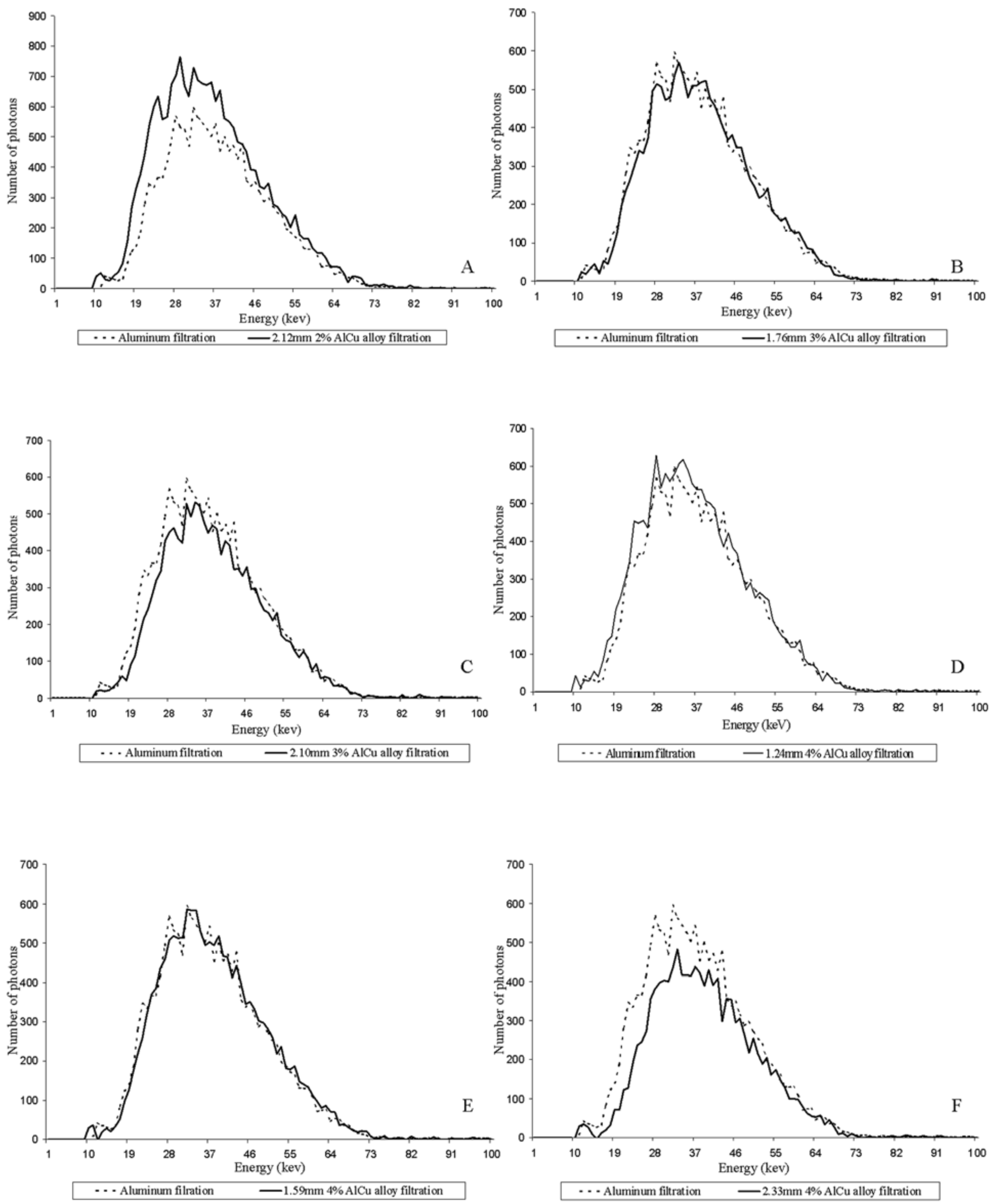

Figure 1. Energy spectra (in keV) comparing aluminum to aluminum-copper alloy filtration, in different percentages and thicknesses, using 70 kVp according to the number of photons.

spectra distribution (Figure 1A-F).

The AlCu 2% alloy filter (2.28 mm thick) showed minor filtration and had similar beam hardening when compared to aluminum filtration (Figure 1-A). The AlCu 3% alloy filter (1.76 mm thick) indicated similar filtration and beam hardening to the aluminum filtration (Figure 1-B). The AlCu 3% alloy filter (2.10 mm thick) showed discreet filtration and similar beam hardening compared to 1.83 mm of aluminum filtration (Figure 1-C). The AlCu 4% alloy filtration (1.24 mm thick and 1.59 mm thick) showed similar filtration and beam hardening to the aluminum filtration (Figures 1-D and 1-E). The AlCu 4% alloy filtration (2.33 mm thick) had a greater filtration and similar beam hardening when compared to 1.83 mm of aluminum filtration (Figure 1-F).

Half value layer determination and air kerma rate

Table 2 also shows the values of HVL (in mm of aluminum equivalent) and air *kerma* rate (in mGy). The data showed a reduced air *kerma* rate for all values of HVL with the aluminum-copper alloy filters.

DISCUSSION

In this study, we did not observe loss of image quality when air *kerma* rate was reduced, whereas the contrast index remained practically the same for all filtration studied. However, reduced x-ray exposure and loss of image quality have been reported in previous studies (3,8,18) while both reduced x-ray exposure and increased exposure time have been reported by others (4-6,8). These observations were not found in our investigation, although we studied air *kerma* rate, not x-ray exposure. The exposure time used with the AlCu alloy filtration was the same or shorter than the one used for exposure of the film with the aluminum filtration, different from previous studies (1,5) when additional filtration plus conventional filtration was used. Our study was not in agreement with that of Haiter et al. (19) who used aluminum zinc alloy filtration and found time exposure increased and air *kerma* rate reduced.

When comparing radiographic images taken with the AlCu alloy and aluminum filtration, similar image quality was noted. These data are in agreement with others findings (7,19). In both the present study and that of Haiter et al. (19), the contrast index remained constant for the radiographic image. Another study (8) reported loss of contrast associated to reduced x-ray exposure when studying yttrium and niobium filtration.

The range of the energy spectrum, between 30 and 41 keV, observed in this study was lower than that observed for samarium filtration, which was between 30 and 50 keV (4), and for niobium filtration, which was between 43.3 and 48 keV (9); however, it was greater than the lower range for samarium filtration, which was between 25 and 45 keV, documented by Duckworth et al. (20).

When using 2.33 mm 4% AlCu alloy filtration, a reduction in high-energy photons was observed, but the exposure time was not increased. These results are different from those reported by Richards (1).

We conclude that there was a reduced air *kerma* rate for all the studied AlCu alloy filters with Ektaspeed Plus film and 70 kVp. Air *kerma* rate reduction of 47.33% for the 2.33 mm AlCu 4% alloy filtration and 23.41% for the 2.10 mm AlCu 3% alloy filtration also showed spectrum alterations when compared to that of aluminum filtration. The other percentages and thicknesses of alloy filtration showed similar performance to aluminum filtration. In the majority of cases, the image taken with the alloy filtration were considered similar or better than those taken with the aluminum filters and when this occurred, there was a preference for images taken with the AlCu 3% alloy filter. Therefore, based on these results, AlCu alloy filtration can be considered as an acceptable alternative to aluminum filtration.

RESUMO

Este estudo avaliou a redução da taxa de *kerma* no ar, o espectro de energia dos raios X e alterações na qualidade da imagem radiográfica. Comparações com várias espessuras do filtro de liga de alumínio-cobre em três diferentes porcentagens foram feitas com o filtro de alumínio. Os experimentos foram feitos utilizando-se um aparelho de raios X odontológico convencional, obtendo radiografias com auxílio de um fantoma de segmento de mandíbula e de uma escala de densidade confeccionada com alumínio laminado. Dependendo da espessura da filtração da liga de alumínio-cobre, o feixe de raios X pôde ser endurecido em relação ao filtro de alumínio. O uso do filtro de liga de alumínio-cobre resultou em 8,40% a 47,33% de redução da taxa média de *kerma* no ar e indicou contraste da imagem radiográfica sem alteração, quando comparado com a filtração de alumínio, mostrando que os filtros de liga de alumínio-cobre tornam-se alternativas aceitáveis em relação aos filtros de alumínio.

ACKNOWLEDGEMENTS

We thank CAPES for the financial support given to conduct this PhD research.

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Accepted March 10, 2003